# Current and Future Changes in Northern Hemisphere Snow Extent and Their Potential Linkages with Atmospheric Circulation
# 현재와 미래의 북반구 눈피복 변화와 대기순환과의 잠재적인 상관성

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Abstract

Snow cover is a potential water resource for later spring and summer seasons as well as a thermal mirror with high reflectivity causing decreases of surface air temperature during cold winter seasons. In this study, current and future changes in Northern Hemisphere snow extent and their potential linkages with atmospheric circulation are examined. The NOAA AVHRR visible snow extent (1967−2006) data as well as observational (NCEP−DOE 1979−2006) and modeled (GFDL 2.1 2081−2100) pressure and surface air temperature data are used. Analyses of observational data demonstrate that the snow extent in meteorological spring (March to April) and summer (June to August) has significantly decreased since the late 1980s. The offset of snow seasons (the timing of snow melt in spring) have also significantly advanced particularly in Europe, East Asia, and northwestern North America. Analyses of pressure fields reveal that the spatial patterns of the earlier snow melt are associated with changes in atmospheric circulation such as the Arctic Oscillation (AO). In the positive winter AO years, multiple positive pressure departure cores in the upper troposphere (200hPa) are observed over the mid−latitude regions from March to mid−April, while a negative pressure departure core (70hPa) prevails over the Arctic Ocean. The reversed anomaly patterns related to later snow melt occur in negative winter AO years. The comparison between current and future thermal spring onsets suggest that snow melt patterns will intensify with larger greenhouse gas emissions, indicating earlier hydrological spring onset.

*Key words*: Northern Hemisphere snow extent, Atmospheric circulation, Arctic Oscillation, hydrological spring onset

## 1. Introduction

Seasonal fluctuations of snow cover have important effects on the spatial and temporal patterns of thermal and hydrological energy on the Earth's surface. Seasonally, snow cover advances toward the lower mid−latitude regions during the second half of the year, but it

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retreats toward the Arctic Ocean during the first half of the year on a hemispheric scale. Maximum snow extent in January covers 47 million $km^2$ of Northern Hemisphere land masses, while its size shrinks to approximately a tenth of the maximum one in August (Robinson&Frei, 2000). During snow seasons, high albedo of snow cover can lower surface air temperature by 4-8° C compared with those over snow-free surfaces (Dewey 1977; Leathers & Robinson 1993; Groisman *et al.* 1994). Snow cover remaining until early spring is recognized as an important hydrological resource for various socio-economic activities including drinking water and irrigation for crops. Moreover, the southmost boundary of snow cover forms a thermal front with largest thermal gradients between snow-covered regions and snow-free regions. Thermal gradient along the snow front may determine spatial patterns of large circulation such jet streams, or circumpolar vortices.

In this study, spatial changes in recent snow cover and their potential associations with atmospheric circulation are examined. In more detail, trends of seasonal Northern Hemisphere snow extent and their potential linkages with atmospheric circulation are examined in section 2.1. In section 2.2, current and future changes in the onsets/offsets and durations of Northern Hemisphere snow seasons are investigated.

In this study, weekly snow cover data for the period 1972-2005 derived from AVHRR visible satellite imagery are used to examine snow extent and seasons. The weekly snow cover data consist of binary format codes (0= snow free, 1= snow covered) based on the National Meteorological Center Limited-Area Fine Mesh 89×89 Cartesian grids laid over a polar stereographic projection (Robinson *et al.* 1993).

## 2. Changes in Northern Hemisphere snow extent and seasons

### 2.1. Changes in snow extent

Phases of Northern Hemisphere snow cover anomalies have been changed from a positive to negative mode since the late 1980s. These decreasing trends in snow extent are observed in both North America and Eurasia. Seasonally, more significant decreasing trends are observed in meterological spring (March-May) and summer (June-August) (Figure 1). In contrast, snow extent anomalies in autumn and winter do not show any noticeable increasing or decreasing trends over the study period. Strong positive spring and summer snow covers are observed between the 1980 period (1976-1985). Since the late 1980s, both spring and summer snow extent shows a negative mode except for 1996 and 1997. Significant decreasing trends at monthly scales are observed between March and June.

These decreasing trends are associated with changes in upper tropospheric circulation patterns. Figure 2 illustrates spatial patterns of early March 200hPa geopotential height anomalies during the 1980 period (1976-1985) versus during the 1990 period (1986-1995). In the 1980 episode, a positive pressure anomaly core has appeared over the Arctic region, while several negative anomaly cores have prevailed over the midlatitude regions. In contrast, pressure patterns between the Arctic region and the midlatitude regions have been reversed in the 1990 episode. A negative anomaly has prevailed a negative anomaly over the Arctic region, while over the midlatitudes, several positive anomaly cores have been predominant. These patterns have lasted from March to mid-April, implying that upper tropospheric circulation patterns are associated with surface snow extent anomaly patterns.

(a) Meteorological spring (March-May) (b)Meteorological summer (June-August)

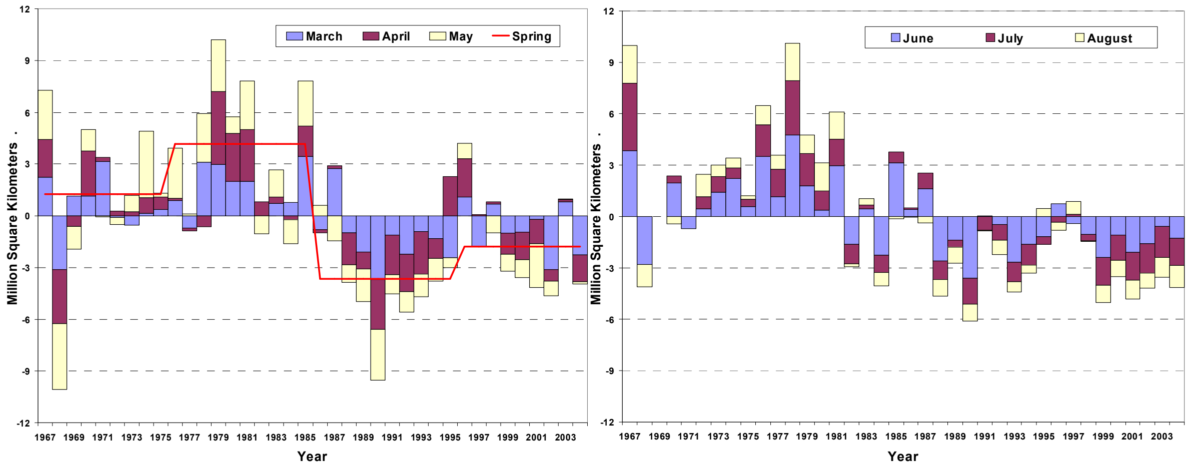


Figure 1. Long-term (1967-2005) variations of Northern Hemisphere snow extent during meteorological spring (March to May) and summer (June to August).

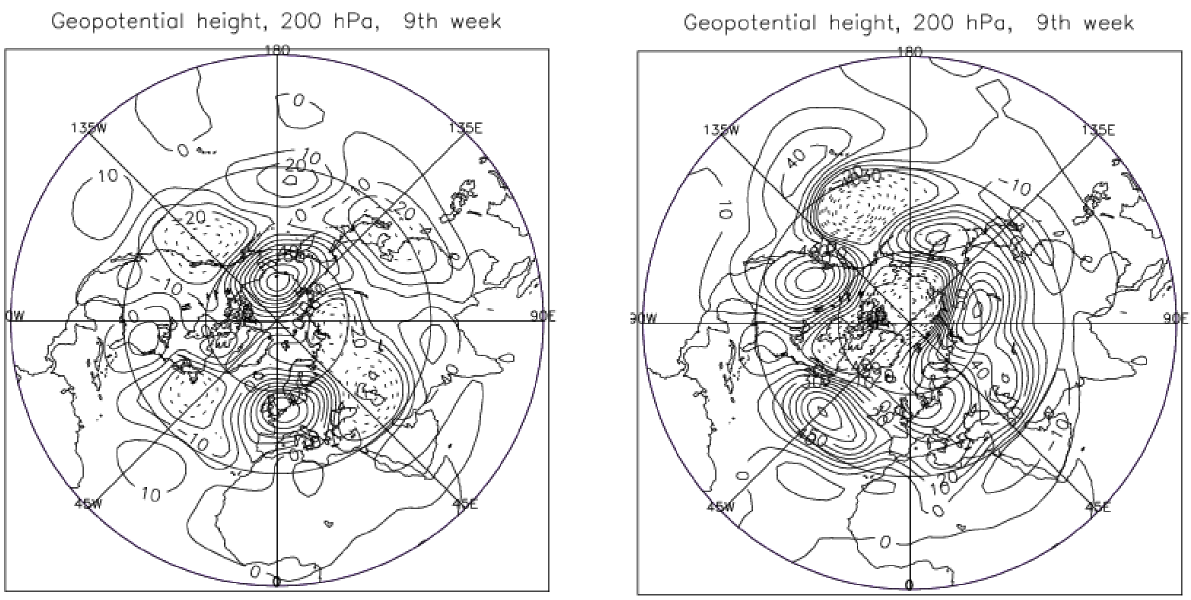


Figure 2. A comparison of Northern Hemisphere 200hPa geopotential height anomalies in the 9th week (early March) between the 1980 period (1976-1985; left) and the 1990 period (1986-1995; right)

### 2.2 Changes in snow seasons

In this study, Full Snow Season (FSS) for discontinuous snow cover events as well as Core Snow Season (CSS) for continuous, long lasting snow cover events in mid-winter are defined. Time series of Northern Hemisphere FSS and CSS durations (Figure 3) demonstrate that the FSS duration has shortened by 5.2 days/decade over the 1972-2005 period, while there has been no noticeable change in the CSS duration. The decreasing trends of the FSS duration are attributable primarily to an earlier FSS offset. Spatially, these earlier FSS offset trends are observed over Europe, central Asia, East Asia as well as along the Rockies. These earlier offset patterns are consistent with the finding by Choi and Robinson (2007), which examined changes in Norhtern Hemisphere thermal seasons based on surface air temperature in recent decades. Choi and Robinson (2007) claimed that thermal spring onset has been advanced in recent decades. These results indicate that hydrological spring onset as well as thermal spring onset has been advanced. Analyses of thermal seasons based on modeled (GF이 2.1) temperature data suggest that snow impossible days (Tmean >= 5 ℃) will increase in the 21st century.

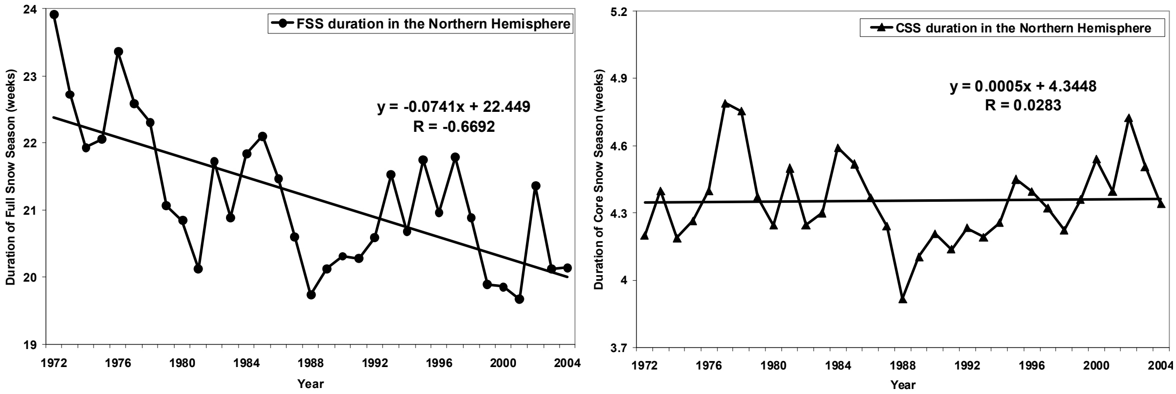


**Figure 3. 500hPa geopotential height anomaly differences between the pre-1988 and post-1987 periods along the western Pacific region (Choi&Kwon, 2008)**

## 3. Conclusion and future studies

This study demonstrated that Northern Hemisphere snow extent has decreased in the first half of the year. It is also found that Northern Hemisphere snow seasons has shortened primarily due to an earlier offset. Modeled data predict that the reduction of snow days as well as the shrinkage of snow seasons will be accelerated with increases of surface air temperature in the 21st century. Analyses of upper tropospheric circulation patterns revealed that the sea-saw oscillation patterns between the Arctic and the mid-latitude pressure cores are associated with surface snow extent and season changes. These patterns may be associated with changes of Arctic Oscillation

(AO) mode. Since the late 1980s, positive AO winter modes have been pronounced. In future studies, the detail of these linkages between surface snow cover regime and upper atmospheric circulation should be examined to develop statistical prediction models of hydrological spring onset.


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## References


1. Choi, G. and Robinson, D.A., 2007, Temporal and spatial changes in Northern Hemisphere floating climatological seasons, *Proceedings of the 2007 National Meeting of the American Geophysical Union (AGU)*, San Francisco, CA, USA.
2. Dewey, K.F., 1977, Daily maximum and minimum temperature forecasts and the influence of snow cover. *Monthly Weather Review*, 105, 1594−1597.
3. Groisman, P.Y., T.R. Karl, R.W. Knight, and G.L. Stenchikov, 1994, Changes of snow cover, temperature, and radiative heat balance over the Northern Hemisphere. *Journal of Climate*, 7, 1633−1656.
4. Leathers, D.J., and D.A., Robinson, 1993: The association between extremes in North American snow cover extent and United States temperatures. *Journal of Climate*, 6, 1345−1355.
5. Robinson, D.A., 1993, Hemispheric snow cover from satellites. *Annals of Glaciology*, 17, 367−371.
6. Robinson D.A. and A. Frei, 2000, Seasonal variability of Northern Hemisphere snow extent using visible satellite data. *The Professional Geographer*, 52, 307-315.